# FRED Reports

Limnological and Fisheries Assessment
of Sockeye Salmon *(Oncorhynchus nerka)*
Production in Afognak Lake

by
L. E. White S. G. Honnold
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Number 103

**Alaska Department of Fish & Game**
Division of Fisheries Rehabilitation,
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Alaska Department of Fish and Game
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## Prologue

"There was a concern about the condition of Litnik (Afognak) Lake and its ability to provide food for the fry released into it so limnological studies were contracted to Rich in 1930. He found a dearth of plankton in the lake and in 1931 samples of young fish showed they were decidedly poorly nourished. This was brought to the attention of the Commissioner of Fisheries, O'Malley, who corresponded with Dr. Chancey Juday, University of Wisconsin, about fertilizing Litnik Lake with phosphate. O'Malley said ..it seems to me as years go by [lake fertilization] is one of the most valuable things we can do. There is certainly no sense in planting fish in waters that are devoid of food, for the fish simply to starve to death in a short time."

O'Malley - 1933
(from Roppel 1982)

# INTRODUCTION

Afognak Lake (also referred to as Litnik Lake) is located 50 km northwest of the city of Kodiak, and is the largest lake on Afognak Island (Figure 1). The sockeye salmon (*Oncorhynchus nerka*) escapement goal set by the Commercial Fish Division is between 40,000 and 60,000 fish. Although escapements for this system have been reached in 10 of the past 12 years, the return per spawner ratio has been poor and not supportive of a significant commercial fishery. Moreover, unlike many other Kodiak area sockeye salmon lakes, Afognak Lake is not responding to changes in the management of this stock. In recent years, the catch and escapement combined exceeded 100,000 sockeye salmon (1982 and 1984); however, as this system is only 20 km from the Kodiak road system, it is receiving ever-increasing sport and subsistence use by Kodiak residents. For example, the subsistence catch more than doubled in 1985 to 6,800 from 3,100 in 1984.

The Kodiak Regional Planning Team (KRPT) and the Kodiak Regional Aquaculture Association (KRAA) have listed Afognak Lake as the highest priority sockeye salmon enhancement project on Afognak Island. A survey conducted by the KRPT in 1983 indicated that sockeye salmon were the preferred species for commercial and subsistence fisherman in the Kodiak area (KRPT 1987).

In 1987 the Alaska Department of Fish and Game (ADF&G), Division of Fisheries Rehabilitation, Enhancement, and Development (FRED), in cooperation with KRAA initiated pre-fertilization fisheries and limnological surveys, which have continued through 1989. Each year, smolts were sampled for age and size, limnology data were collected, hydroacoustic surveys were conducted, and morphometric information was ascertained. Since 1978, the Commercial Fish Division of ADF&G has operated an adult salmon weir to obtain escapements and to sample adult sockeye salmon for age and length information. In addition, during 1987 and 1988, adult sockeye salmon were sampled for disease screening in the event this stock was needed as a broodsource.

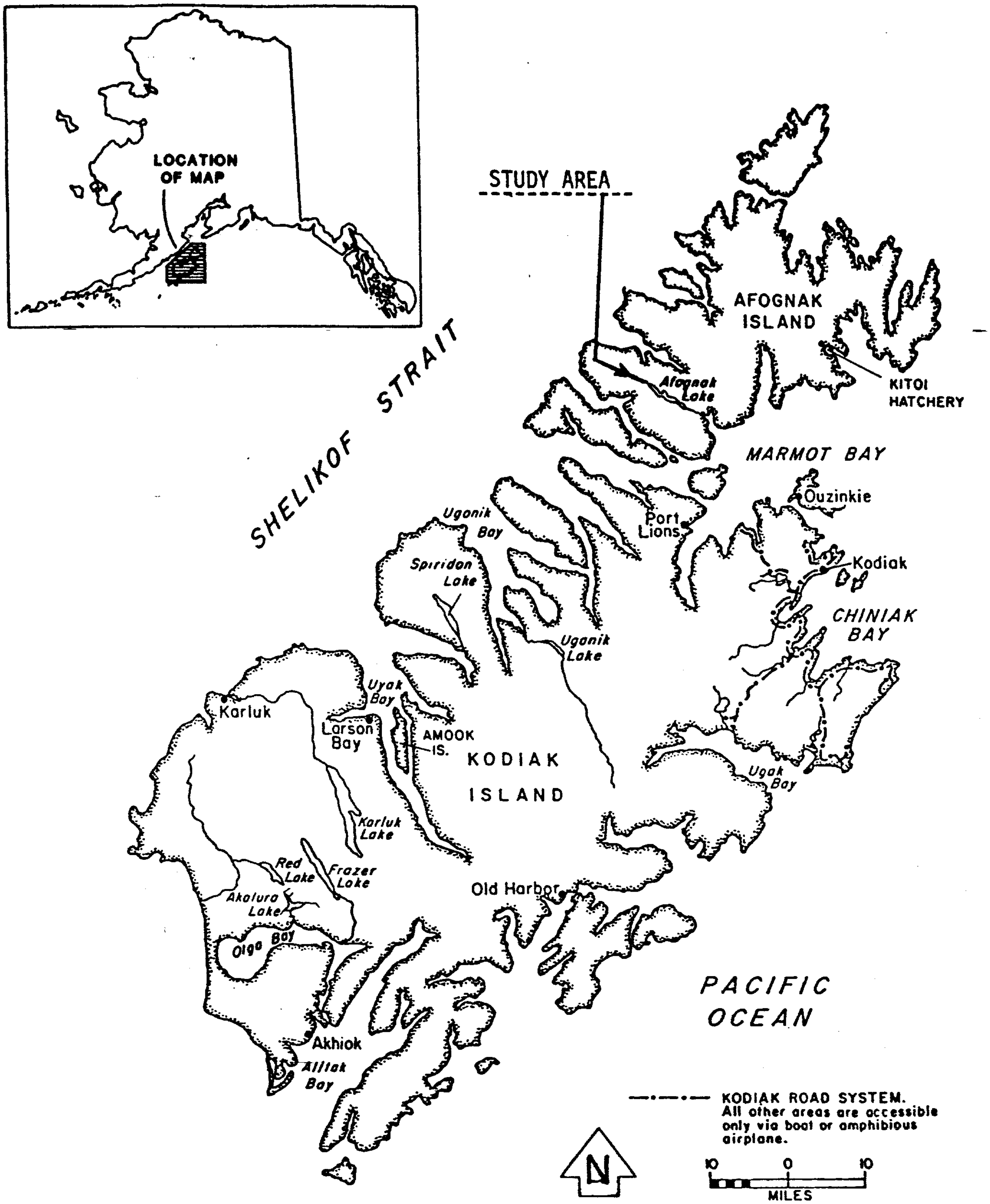


Figure 1. Area map of Kodiak and Afognak Islands showing location of Afognak Lake.

The purpose of this report is to summarize fisheries and limnological investigations relative to assessing sockeye salmon production, the enhancement potential, and the appropriate type of enhancement relevant to the productivity status of Afognak Lake.

## Description of Study Area

Afognak Lake (58° 07'N, 152° 55' W) lies at an elevation of 21 m, is 8.8 km long, up to 0.8 km wide, and has a total surface area of 5.3 million X $10^6$ $m^2$ (Figure 2). This lake is relatively shallow, with a mean depth of 8.6 m and a maximum depth of 23 m, and is characterized as an oligotrophic system. Because of the relative shallowness of this lake, warm surface water temperatures, and deep mixing, a large volume of water is heated during June through September. The annual precipitation on Afognak Island averages 155 cm, and the lake-water residence time is 0.4 years.

Afognak Lake was the site of a large federal government sockeye salmon hatchery. During 1908-1933, the hatchery released sockeye salmon fry into Afognak Lake and shipped eggs to other facilities in Alaska and to other states. During its peak year of production over 79 million eggs were incubated. The facility closed after many years of marginal returns and controversy over widespread hatchery issues (Hunt 1976; Roppel 1982). In addition, sockeye salmon eggs were also stocked into Afognak Lake from other facilities.

Sockeye salmon returning to Afognak Lake begin migrating in mid-May and end in late-September. Sockeye salmon weir escapements over the past 12 years have ranged from 26,000 to 123,000, and averaged 67,000. The fish spawn from the end of July into October, and as with other sockeye salmon stocks in the Kodiak area, the earliest spawning begins in the cooler tributaries, while latter spawning occurs in the lakeshore areas. A high percentage of sockeye salmon in Afognak Lake utilize the lakeshore for spawning (Willette 1984).

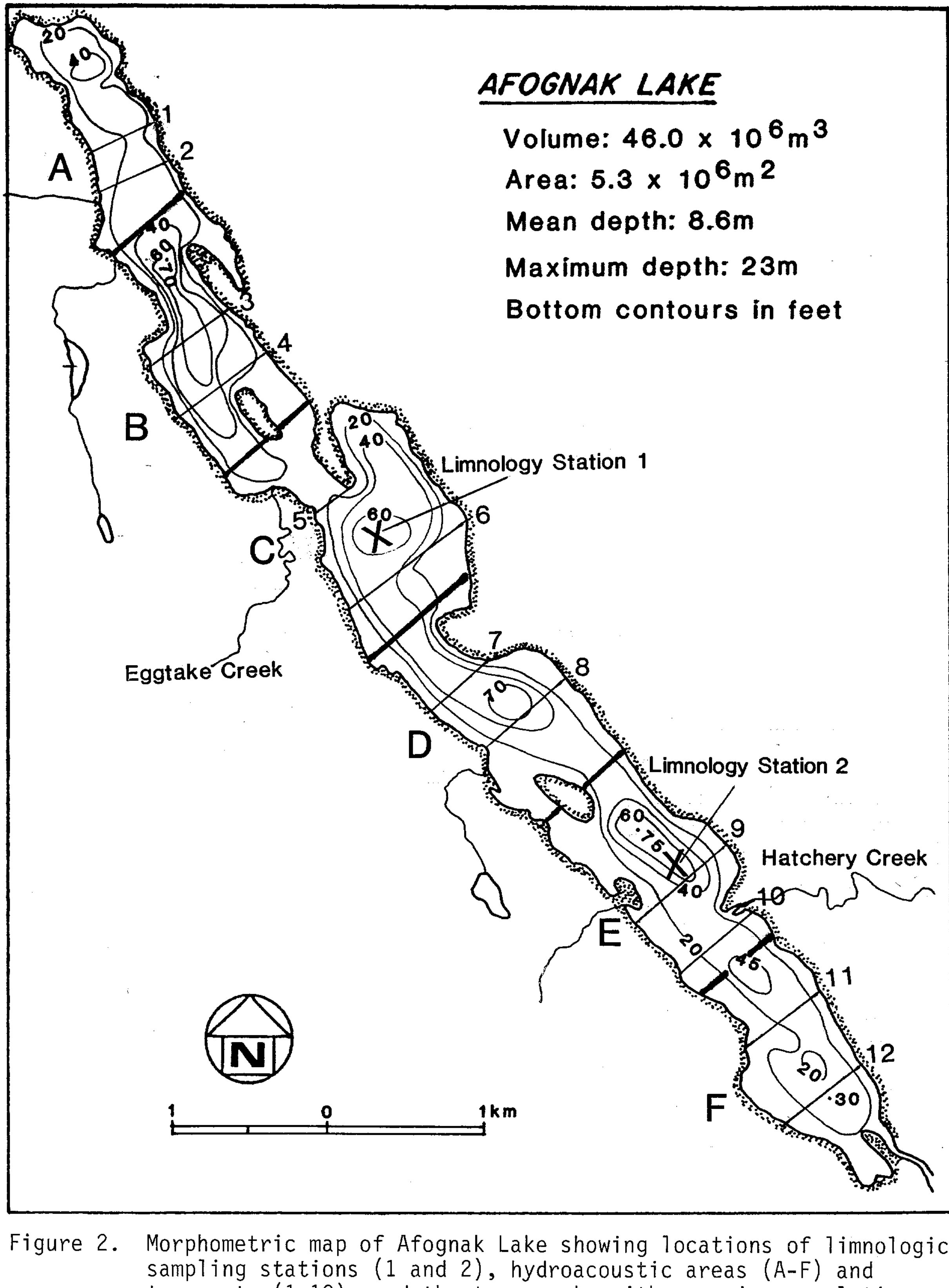


Figure 2. Morphometric map of Afognak Lake showing locations of limnological sampling stations (1 and 2), hydroacoustic areas (A-F) and transects (1-12), and the two creeks with spawning populations of sockeye salmon.

Other fishes of Afognak Lake include: pink salmon (*O. gorbuscha*), coho salmon (*O. kisutch*), chum salmon (*O. keta*), chinook salmon (*O. tshawytscha*), rainbow or steelhead trout (*O. mykiss*), Dolly Varden char (*Salvelinus malma*), three spine stickleback (*Gasterosteus aculeatus*), and freshwater sculpin (*Cottus aleuticus*) (Roelofs 1964; ADF&G unpublished survey reports).

## METHODS AND MATERIALS

### Juvenile and Adult Salmon Assessment

**Smolt Sampling--** Sockeye salmon smolts were collected and sampled for age, weight, and length during 1987-1989. Approximately 200 smolts were collected each year using a fyke net located at the adult weir site near the lake outlet. Smolts were anesthetized in a tricaine methanesulfonate (MS-222) solution, measured to the nearest millimeter (snout-to-fork of tail), and weighed to the nearest 0.1 g. In addition, a scale smear was taken from each measured fish, placed on a glass slide, and ages were determined using a microfische projector.

**Hydroacoustic Surveys--** A spring (May) and fall (September) hydroacoustic survey was conducted in 1989 to estimate the number and distribution of juvenile fish/sockeye salmon fingerlings rearing in Afognak Lake. Hydroacoustic surveys comprised of recording data along twelve transects perpendicular to the longitudinal axis of the lake (Figure 2). The lake was divided into six equal areas (A-F) and two transects per area were selected randomly. Recording of down-looking acoustic data along the transects was done at night because juvenile sockeye salmon are more evenly dispersed. Flashing stobe lights were placed at both ends of each transect to assist in maintaining transect course. A BioSonics® model 105 echosounder system

®Mention of commercial products and trade names does not constitute endorsement by ADF&G, FRED Division.

with 6/15° dual-beam transducer was used. Fish signals were recorded electronically using a Sony digital video cassette recording system and on chart paper using a BioSonics model 115 recorder.

Analysis of the recorded hydroacoustic tapes was conducted by Dr. Richard Thorne of BioSonics, Inc. Fish densities were low enough during the May survey that echo counting techniques (Thorne 1983) could be used. The number of echoes from fish targets were counted in 1-min increments along the 12 transects and in six depth intervals. Sampling volumes were estimated by the duration-in-beam technique (Nunnallee and Mathisen 1972; Nunnallee 1980; Thorne 1988). For each depth interval and 1-min increment, fish densities (no./$m^3$) were summed to determine the total areal fish density (no./$m^2$) for each transect. Mean transect fish densities were weighted by time, since end-of-transect increments were usually less than 1 min. A mean areal fish density and an associated variance was computed from the two transects per area (Kyle 1989). The total fish population estimate was obtained by multiplying the lake area representing each area by the calculated fish density for that respective area. Transect variances were summed and a 95% confidence interval for the total fish population estimate was calculated for each survey (Kyle 1989). Finally, identification of acoustic targets as to fish species was made using a 2 m x 2 m townet (Gjernes 1979). During the May and September surveys, two 30-min tows were conducted along the axis of the lake.

**Adult Surveys and Sampling--** Adult escapement counts were conducted by the Commercial Fish Division of ADF&G using a weir placed near the lake outlet. Since 1978, the Afognak Lake weir has operated yearly from May through September. Since 1985, 500-1,000 adult sockeye salmon were sampled each year at the weir site for age composition. A scale smear was taken from each sampled fish, and ages were determined from acetate impresssions using a microfische projector. Spawning area surveys and previous weir counts have been conducted intermittently on Afognak Lake since 1913. In addition, 60 adult sockeye salmon were sampled for the incidence of hematopoietic necrosis virus (IHN) and bacteria kidney disease (BKD) during 1987 and 1988.

## Limnological Assessment

**Water Sampling--** Lake assessment surveys were conducted during 1987-1989. Transportation to and from Afognak Lake was provided by a float-equipped aircraft; limnological samples were collected after mooring to the two permanent sampling stations (Figure 2). The frequency of sampling was designed to characterize the lake from ice-off in the spring to ice-on in the winter. Lake water was sampled at the 1 m (epilimnion) and 10-20 m (hypolimnion) zones for algal nutrients (nitrogen, phosphorus, silicon, and carbon) as well as general water quality parameters. Water samples from multiple casts with a non-metalic Van Dorn sampler were pooled, stored in 8-10 L translucent carboys, and immediately transported to Kodiak for filtering and preservation. Subsequent filtered and unfiltered water samples were stored either refrigerated or frozen in acid-cleaned, pre-rinsed polybottles. The pre-processed water samples were then sent to the ADF&G Limnology Laboratory in Soldotna for analysis.

**Physical Features--** The collection of physical data included the measurement of lake temperatures and light penetration at both Stations 1 and 2 (Figure 2). Lake temperature/dissolved oxygen profiles were measured using a YSI model 57 meter. These recordings were taken at 1-m increments from the surface to 5 m, and at 2-m increments from 6 m to the bottom of the lake. The algal light compensation point was defined as the depth at which 1% of the subsurface light (photosynthetically available radiation [400-700 mm]) penetrated (Schindler 1971), and it was measured using a Protomatic submersible photometer. Recordings were taken every 0.5 m to 5 m, and every 1 m down to the light compensation depth. Water clarity was also measured with a 20-cm Secchi disk by recording the depth at which the disk disappeared from view.

**Morphometry and Water Residence Time--** Bottom profiles were recorded with a fathometer along numerous lake transects, and used to develop a bathymetric map. The area of each depth strata was determined with a polar planimeter, and the lake volume (V) was computed by summation of successive strata (Hutchinson 1957), and mean lake depth determined from:

$$z = V/A_L$$

Where: $z$ = lake mean depth (m)

$V$ = lake volume ($\cdot 10^6 m^3$)

$A_L$ = lake surface area ($\cdot 10^6 m^2$).

The theoretical water residence time was calculated using the following formula (Koenings et al. 1987):

$$T_w\ (yr) = V/TLO$$

Where: $T_w$ = theoretical water residence time (years)

$V$ = total lake volume ($\cdot 10^6 m^3$)

$TLO$ = total lake outflow ($\cdot 10^6 m^3/yr$).

**Nutrients--** All chemical and biological samples were analyzed by methods detailed by Koenings et al. (1987). In general, filterable reactive phosphorus (FRP) was analyzed by the molybdate-blue/ascorbic-acid method of Murphy and Riley (1962), as modified by Eisenreich et al. (1975). Total phosphorus was determined by FRP procedure, after persulfate digestion. Nitrate and nitrite ($NO_3 + NO_2$) were determined as nitrite, following Stainton et al. (1977), after cadmium reduction of nitrate. Total Kjeldahl nitrogen (TKN) was determined as total ammonia following sulfuric acid block digestion (Crowther et al. 1980). Total nitrogen was calculated as the sum of TKN and $NO_3 + NO_2$. Reactive silicon was determined using the method of ascorbic acid reduction to molybdenum-blue after Stainton et al. (1977). Alkalinity levels were determined by acid titration (0.02 N $H_2SO_4$) to pH 4.5, using a Corning model-399A specific ion meter. Finally, particulate carbon, nitrogen, and phosphorus were estimated directly from filtered seston that was prepared by drawing 1-2 L of lake water through pre-cleaned 4.2-cm GF/F filters. The filters were stored frozen in individually marked plexislides until analyzed.

Estimates of yearly phosphorus loading in Afognak Lake were calculated after Vollenweider (1976):

Surface specific loading:

$$Lp(mgP/m^2/yr) = \frac{[P]^{sp} \times \bar{z}(1+\sqrt{T_w})}{T_w}$$

Surface critical loading:

$$Lc(mgP/m^2/yr) = \frac{10mgP/m^3 \times \bar{z}(1+\sqrt{T_w})}{T_w}$$

Permissible supplemental P (mg/m$^2$/yr) loading = $L_c \cdot 90\% - L_p$

Where: $[P]^{sp}$ = spring overturn period total P (mg/m$^3$)

$\bar{z}$ = mean depth (m)

$t_w$ = water resident time (y)

10 mgP/m$^3$ = lower critical phosphorous level.

**Chlorophyll a--** Algal standing crop was estimated by chlorophyll a (chl a) analysis, after the fluorometric procedure of Strickland and Parsons (1972). The low-strength acid addition recommended by Riemann (1978) was used to estimate phaeophytin. Water samples (1-2 L) were filtered through 4.25-cm GF/F filters to which 1-2 mls of a saturated $MgCO_3$ solution were added just prior to the completion of filtration. The filters were then stored frozen in individual plexislides for later analysis.

**Zooplankton--** Zooplankton were enumerated from duplicate 15-m (Station 1) and 10-m (Station 2) vertical tows using a 0.2-m diameter (153-um mesh) conical net. The net was pulled at a constant 1 m/s, and all organisms were preserved in a 10% neutralized formalin solution. Identification of *Daphnia* followed Brooks (1957), *Bosmina* after Pennak (1978), and the copepods after both Wilson (1959) and Yeatman (1959). Enumeration consisted of counting triplicate 1-ml subsamples taken with a Hansen-Stempel pipette in a 1-ml Sedgewick-Rafter cell. Finally, zooplankton body sizes were obtained by measuring the length to the nearest 0.01 mm of at least 10 individuals along a transect in each 1-ml subsample (Koenings et al. 1987).

## RESULTS AND DISCUSSION

### Juvenile and Adult Salmon Assessment

**Smolt Sizes and Age Compositions--** During 1987-1989, sampled age-1 smolts migrating from Afognak Lake averaged between 74.9 and 77.9 mm in length and 3.6 and 4.1 g in weight (Table 1). Condition factors for age-1 smolts ranged between 0.85 and 0.91. Age-2 smolts were found in significant numbers only in 1987. Their mean size was 79.3 mm and 4.3 g with a condition factor of 0.86. The age compositions of the sampled smolts revealed a dominance of age-1 smolts in 1988 and 1989 (100% and 99.1%), and a dominance of age-2 smolts in 1987 (83.8%) (Table 2).

Each year, the smolts sampled from Afognak Lake were collected once (mid-June) during the migration, which may have biased both mean size and age composition. That is, the age structure of migrating smolts are known to change throughout the migrational period; older smolts tend to migrate earlier, while younger smolts migrate

Table 1. Length, weight, and condition factor of sockeye salmon smolts sampled at Afognak Lake, 1987-1989.

| Date sampled | Age | Sample size | Mean length | Mean weight | Mean condition factor |
|---|---|---|---|---|---|
| 06/08/87 | 1 | 36 | 74.9 | 3.6 | 0.85 |
| 06/08/87 | 2 | 186 | 79.3 | 3.6 | 0.86 |
| 06/16/88 | 1 | 202 | 77.9 | 4.1 | 0.90 |
| 06/16/88 | 2 | -- | -- | -- | -- |
| 06/16/89 | 1 | 208 | 76.8 | 4.1 | 0.91 |
| 06/16/89 | 2 | 2 | 78.0 | 5.2 | 1.10 |

Table 2. Age composition of sockeye salmon smolts sampled at Afognak Lake, 1987-1989.

| | | Age composition (%) | | | | |
|---|---|---|---|---|---|---|
| Date sampled | Sample size | 0 | 1 | 2 | 3 | Total |
| 06/08/87 | 222 | 0.0 | 16.2 | 83.8 | 0.0 | 100.0 |
| 06/15/88 | 203 | 0.0 | 100.0 | 0.0 | 0.0 | 100.0 |
| 06/15/89 | 211 | 0.0 | 99.1 | 0.9 | 0.0 | 100.0 |

later (Roelofs 1964; White 1986). Roelofs (1964) operated a smolt weir near the outlet of Afognak Lake in 1963 and found that the peak smolt migration occurred between May 27 and June 10, and reported a mean fork length of 74.5 mm for age-1 smolts and 82.8 mm for age-2 smolts, which were similar to the sizes recorded during mid-June of 1987-1989.

**Juvenile Fish Population Estimates and Distributions--** The May 09 hydroacoustic survey conducted in 1989 revealed a population estimate of limnetically-rearing juvenile fish of 412,925 $\pm$ 59,939 (Table 3). Transects 3-8 (Figure 2), representing lake areas B-D located approximately in the middle one-third of the lake, had the highest density and population of juvenile fish. In the September 05 survey of 1989, the juvenile fish population estimate was much greater at 3,750,325 $\pm$ 1,105,078 (Table 4). Transects 3-6 representing lake areas B and C had the highest density and population of juvenile fish. The vertical distribution of juvenile fish was similar for both surveys; the majority of fish were found in the upper two depth intervals of 2-5 m and 5-9.5 m (Tables 5 and 6). In general, it appears rearing juvenile fish in Afognak Lake are centrally distributed, undergo diel vertical migration (migrate to the surface at night to feed), and do not tend to rear at deep depths in potentially sub-optimal tempertures for growth.

Townetting resulted in no catches in the May survey, and a total of 38 sticklebacks and only one sockeye salmon fingerling in the September survey. Thus, townetting results indicate a high proportion of sticklebacks in the September survey, but low catches of both species preclude apportioning the total population estimate of juvenile fish.

**Adult Returns and Age Compositions--** Weir counts of sockeye salmon indicate that escapements during 1978-1989 were considerably higher than during earlier years (1913-1963) (Table 7). That is, during 1921-1933, 12 years of sockeye salmon weir counts averaged 19,958, while during 1978-1989 the average count was 65,471.

Table 3. Fish population estimates and variances for paired transect areas of Afognak Lake, 09 May 1989.

| Area | Transect | Mean fish density (no./1000 $m^2$) | Area ($\times$ 1000 $m^2$) transect | Area ($\times$ 1000 $m^2$) total | Weighted mean fish density (no./1000 $m^2$) | Variance (X 1000) | Total area ($\times$ 1000 $m^2$) | Fish pop. | Variance |
|---|---|---|---|---|---|---|---|---|---|
|  | 1 | 36 | 400 |  |  |  |  |  |  |
| 1 |  |  |  | 900 | 53.8 | 252.8 | 900 | 48,400 | 2.0E+08 |
|  | 2 | 68 | 500 |  |  |  |  |  |  |
|  | 3 | 106 | 275 |  |  |  |  |  |  |
| 2 |  |  |  | 825 | 114.0 | 32.0 | 825 | 94,050 | 2.2E+07 |
|  | 4 | 118 | 550 |  |  |  |  |  |  |
|  | 5 | 136 | 200 |  |  |  |  |  |  |
| 3 |  |  |  | 925 | 94.5 | 476.0 | 925 | 87,375 | 4.1E+08 |
|  | 6 | 83 | 725 |  |  |  |  |  |  |
|  | 7 | 120 | 250 |  |  |  |  |  |  |
| 4 |  |  |  | 800 | 108.3 | 62.1 | 800 | 86,650 | 4.0E+07 |
|  | 8 | 103 | 550 |  |  |  |  |  |  |
|  | 9 | 41 | 350 |  |  |  |  |  |  |
| 5 |  |  |  | 700 | 60.0 | 361.0 | 700 | 42,000 | 1.8E+08 |
|  | 10 | 79 | 350 |  |  |  |  |  |  |
|  | 11 | 77 | 350 |  |  |  |  |  |  |
| 6 |  |  |  | 850 | 64.1 | 117.2 | 850 | 54,450 | 8.5E+07 |
|  | 12 | 55 | 500 |  |  |  |  |  |  |
|  |  |  |  |  |  |  | Total | 412,925 | 9.4E+08 |
|  |  |  |  |  | 95% confidence interval (+/-) |  |  |  | 59,939 |

Table 4. Fish population estimates and variances for paired transect areas of Afognak Lake, 05 September 1989.

| Area | Transect | Mean fish density (no./1000 $m^2$) | Area ($\times$ 1000 $m^2$) transect | Area ($\times$ 1000 $m^2$) total | Weighted mean fish density (no./1000 $m^2$) | Variance (X1000) | Total area ($\times$ 1000 $m^2$) | Fish pop. | Variance |
|---|---|---|---|---|---|---|---|---|---|
| | 1 | 130 | 400 | | | | | | |
| 1 | | | | 900 | 556.7 | 145635.6 | 900 | 501,000 | 1.2E+11 |
| | 2 | 898 | 500 | | | | | | |
| | 3 | 1411 | 275 | | | | | | |
| 2 | | | | 825 | 1019.7 | 76570.9 | 825 | 841,225 | 5.2E+10 |
| | 4 | 824 | 550 | | | | | | |
| | 5 | 740 | 200 | | | | | | |
| 3 | | | | 925 | 992.4 | 17571.0 | 925 | 917,950 | 1.5E+10 |
| | 6 | 1062 | 725 | | | | | | |
| | 7 | 636 | 250 | | | | | | |
| 4 | | | | 800 | 747.4 | 5638.4 | 800 | 597,900 | 3.6E+09 |
| | 8 | 798 | 550 | | | | | | |
| | 9 | 1363 | 350 | | | | | | |
| 5 | | | | 700 | 853.0 | 260100.0 | 700 | 597,100 | 1.3E+11 |
| | 10 | 343 | 350 | | | | | | |
| | 11 | 289 | 350 | | | | | | |
| 6 | | | | 850 | 347.2 | 2373.9 | 850 | 295,150 | 1.7E+09 |
| | 12 | 388 | 500 | | | | | | |
| | | | | | | | Total | 3,750,325 | 3.2E+11 |
| | | | | | | 95% confidence interval (+/-) | | | 1,105,078 |

Table 5. Density of fish (no. per m^2) by depth and one-third sections along the 12 hydroacoustic transects on Afognak Lake, 09 May 1989.

| | | Depth interval (m) | | | | | |
|---|---|---|---|---|---|---|---|
| Tansect | Section | 2-5 | 5-9.5 | 9.5-14 | 14-18.5 | 18.5-23 | 23-27.5 |
| 1 | E | 0.0 | 0.0 | 2.8 | 0.0 | 0.0 | 0.0 |
| | M | 0.0 | 8.8 | 3.6 | 0.0 | 0.0 | 0.0 |
| | W | 2.8 | 10.3 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2 | E | 3.8 | 6.2 | 4.3 | 4.9 | 0.0 | 0.0 |
| | M | 0.0 | 6.2 | 6.8 | 5.5 | 0.0 | 0.0 |
| | W | 3.8 | 7.0 | 0.9 | 0.0 | 0.0 | 0.0 |
| 3 | E | 4.3 | 0.0 | 8.7 | 4.9 | 4.9 | 0.0 |
| | M | 4.2 | 7.0 | 2.9 | 1.4 | 5.4 | 2.6 |
| | W | 8.2 | 8.3 | 3.7 | 5.9 | 3.6 | 0.0 |
| 4 | E | 7.9 | 27.2 | 9.7 | 0.6 | 0.0 | 0.0 |
| | M | 4.1 | 4.1 | 2.3 | 2.0 | 5.6 | 0.0 |
| | W | 2.0 | 7.4 | 4.5 | 4.2 | 4.1 | 0.2 |
| 5 | E | 20.7 | 22.4 | 0.0 | 0.0 | 0.0 | 0.0 |
| | M | 34.5 | 8.4 | 0.0 | 0.0 | 0.0 | 0.0 |
| | W | 25.9 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 6 | E | 12.5 | 22.3 | 0.0 | 0.0 | 0.0 | 0.0 |
| | M | 1.5 | 2.4 | 2.0 | 3.0 | 3.0 | 0.0 |
| | W | 3.0 | 4.9 | 5.4 | 0.0 | 0.0 | 0.0 |
| 7 | E | 0.0 | 12.9 | 16.4 | 0.0 | 0.0 | 0.0 |
| | M | 17.2 | 26.3 | 0.0 | 0.0 | 0.0 | 0.0 |
| | W | 10.6 | 6.5 | 0.0 | 0.0 | 0.0 | 0.0 |
| 8 | E | 21.6 | 10.5 | 1.9 | 0.0 | 0.0 | 0.0 |
| | M | 3.8 | 4.7 | 2.1 | 0.5 | 0.5 | 0.0 |
| | W | 23.0 | 10.1 | 1.3 | 0.2 | 0.2 | 0.0 |
| 9 | E | 10.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | M | 6.9 | 7.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | W | 7.7 | 1.6 | 0.0 | 0.0 | 0.0 | 0.0 |
| 10 | E | 29.6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | M | 14.4 | 3.5 | 3.9 | 0.0 | 0.0 | 0.0 |
| | W | 14.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 11 | E | 18.8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | M | 28.2 | 1.3 | 0.0 | 0.0 | 0.0 | 0.0 |
| | W | 17.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 12 | E | 19.7 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | M | 13.8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | W | 13.8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Distribution by depth for all transects (%) | | 51.7 | 29.9 | 10.5 | 4.2 | 3.4 | 0.4 |

Table 6. Density of fish (no. per m^2) by depth and one-minute sections along the 12 hydroacoustic transects on Afognak Lake, 05 September 1989.

| | | | Depth interval (m) | | | | | |
|---|---|---|---|---|---|---|---|---|
| Tansect | Section | Direction | 2-5 | 5-9.5 | 9.5-14 | 14-18.5 | 18.5-23 | 23-27.5 |
| 1 | 1 | E | 45.7 | 3.7 | 0.0 | 0.0 | 0.0 | 0.0 |
| | 2 | \| | 84.8 | 83.4 | 0.0 | 0.0 | 0.0 | 0.0 |
| | 3 | \| | 63.1 | 33.2 | 0.0 | 0.0 | 0.0 | 0.0 |
| | 4 | \| | 2.8 | 37.7 | 0.0 | 0.0 | 0.0 | 0.0 |
| | 5 | W | 3.7 | 2.1 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2 | 1 | W | 34.0 | 85.9 | 0.0 | 0.0 | 0.0 | 0.0 |
| | 2 | \| | 265.7 | 259.2 | 0.0 | 0.0 | 0.0 | 0.0 |
| | 3 | \| | 233.3 | 167.4 | 56.7 | 0.0 | 0.0 | 0.0 |
| | 4 | \| | 191.2 | 23.3 | 20.8 | 108.9 | 0.0 | 0.0 |
| | 5 | \| | 40.2 | 67.0 | 93.6 | 174.7 | 0.0 | 0.0 |
| | 6 | \| | 42.4 | 72.6 | 70.0 | 82.0 | 0.0 | 0.0 |
| | 7 | E | 261.4 | 385.6 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3 | 1 | E | 72.3 | 13.3 | 22.2 | 158.4 | 271.4 | 0.0 |
| | 2 | \| | 8.2 | 16.5 | 46.9 | 214.5 | 48.7 | 0.0 |
| | 3 | \| | 109.9 | 77.6 | 14.2 | 179.0 | 59.0 | 0.0 |
| | 4 | W | 178.0 | 33.0 | 19.3 | 169.6 | 44.9 | 0.0 |
| 4 | 1 | W | 104.6 | 16.7 | 52.0 | 93.4 | 42.5 | 0.0 |
| | 2 | \| | 6.3 | 2.1 | 436.0 | 119.1 | 42.4 | 0.0 |
| | 3 | \| | 3.3 | 21.6 | 70.3 | 130.7 | 45.3 | 0.0 |
| | 4 | \| | 11.1 | 25.8 | 137.2 | 276.6 | 48.3 | 0.0 |
| | 5 | E | 36.2 | 30.6 | 0.0 | 0.0 | 0.0 | 0.0 |
| 5 | 1 | E | 511.6 | 55.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | 2 | \| | 78.3 | 69.9 | 0.0 | 0.0 | 0.0 | 0.0 |
| | 3 | W | 180.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 6 | 1 | W | 314.5 | 220.4 | 19.3 | 0.0 | 0.0 | 0.0 |
| | 2 | \| | 125.9 | 164.2 | 37.5 | 4.9 | 0.0 | 0.0 |
| | 3 | \| | 15.4 | 141.8 | 11.6 | 5.5 | 0.0 | 0.0 |
| | 4 | \| | 185.4 | 42.8 | 118.9 | 3.2 | 0.0 | 0.0 |
| | 5 | \| | 233.3 | 40.8 | 77.9 | 10.2 | 0.0 | 0.0 |
| | 6 | \| | 183.9 | 108.4 | 22.0 | 0.0 | 0.0 | 0.0 |
| | 7 | E | 104.1 | 58.8 | 0.0 | 0.0 | 0.0 | 0.0 |
| 7 | 1 | E | 90.0 | 37.5 | 54.6 | 0.0 | 0.0 | 0.0 |
| | 2 | \| | 6.4 | 110.8 | 74.9 | 0.0 | 0.0 | 0.0 |
| | 3 | W | 219.5 | 121.3 | 0.0 | 0.0 | 0.0 | 0.0 |
| 8 | 1 | W | 92.1 | 238.3 | 15.0 | 0.0 | 0.0 | 0.0 |
| | 2 | \| | 76.1 | 51.9 | 29.3 | 10.5 | 15.4 | 0.0 |
| | 3 | \| | 8.2 | 32.8 | 46.2 | 23.8 | 0.5 | 0.0 |
| | 4 | E | 122.4 | 223.3 | 68.6 | 42.5 | 0.0 | 0.0 |
| 9 | 1 | E | 0.6 | 48.4 | 54.5 | 0.0 | 0.0 | 0.0 |
| | 2 | \| | 3.7 | 23.8 | 225.6 | 0.0 | 0.0 | 0.0 |
| | 3 | \| | 105.0 | 317.7 | 98.1 | 0.0 | 0.0 | 0.0 |
| | 4 | \| | 385.6 | 168.1 | 148.8 | 0.0 | 0.0 | 0.0 |
| | 5 | W | 994.7 | 396.1 | 0.0 | 0.0 | 0.0 | 0.0 |

-Continued-

Table 6 continued. Density of fish (no. per m^2) by depth and one-minute sections along the 12 hydroacoustic transects on Afognak Lake, 05 September 1989.

| | | | Depth interval (m) | | | | | |
|---|---|---|---|---|---|---|---|---|
| Tansect | Section | Direction | 2-5 | 5-9.5 | 9.5-14 | 14-18.5 | 18.5-23 | 23-27.5 |
| 10 | 1 | W | 194.6 | 87.6 | 0.0 | 0.0 | 0.0 | 0.0 |
| | 2 | \| | 37.4 | 208.8 | 0.0 | 0.0 | 0.0 | 0.0 |
| | 3 | \| | 50.3 | 123.9 | 0.0 | 0.0 | 0.0 | 0.0 |
| | 4 | \| | 81.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | 5 | \| | 44.7 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | 6 | \| | 5.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | 7 | E | 43.7 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 11 | 1 | W | 106.7 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | 2 | \| | 114.8 | 68.6 | 26.1 | 0.0 | 0.0 | 0.0 |
| | 3 | \| | 25.0 | 98.9 | 15.9 | 0.0 | 0.0 | 0.0 |
| | 4 | \| | 147.6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | 5 | E | 16.9 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 12 | 1 | W | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | 2 | \| | 596.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | 3 | \| | 482.8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | 4 | \| | 114.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | 5 | \| | 200.9 | 497.4 | 0.0 | 0.0 | 0.0 | 0.0 |
| | 6 | \| | 343.5 | 706.2 | 0.0 | 0.0 | 0.0 | 0.0 |
| | 7 | E | 187.9 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Distribution by depth for all transects combined (%) | | | 45.0 | 30.9 | 11.4 | 9.4 | 3.2 | 0.0 |

Table 7. Estimates of adult sockeye salmon returning to Afognak Lake, 1913-1989.

| Return year | Survey method | Date surveyed | Escapement count | Commercial harvest | Subsistence harvest | Total return |
|---|---|---|---|---|---|---|
| 1913 | weir | - | 3,367 | - | - | - |
| No historical data found from 1914 through 1920. | | | | | - | |
| 1921 | weir | - | 37,653 | - | - | - |
| 1922 | weir | - | - | - | - | - |
| 1923 | weir | - | 8,025 | - | - | - |
| 1924 | weir | - | 10,317 | - | - | - |
| 1925 | weir | - | 11,000 | - | - | - |
| 1926 | weir | - | 22,250 | - | - | - |
| 1927 | weir | - | 7,491 | - | - | - |
| 1928 | weir | - | 20,862 | - | 500 | - |
| 1929 | weir | - | 25,428 | - | - | - |
| 1930 | weir | - | 6,238 | - | - | - |
| 1931 | weir | - | 30,515 | - | - | - |
| 1932 | weir | - | 23,574 | - | - | - |
| 1933 | weir | - | 36,144 | - | - | - |
| Mean 1921-1933 | | | 19,958 | | | |
| No historical data found from 1934-1960. | | | | | | |
| 1961 | weir | - | 38,980 | 24,000 | - | 62,980 |
| No historical data found for 1960. | | | | | | |
| 1963 | weir | 08/24 | 40,600 | - | 1,200 | - |
| No historical data found in 1964 or 1965. | | | | | | |
| 1966 | plane | 07/23 | 950 | - | - | - |
| 1967 | plane | 08/22 | 550 | - | - | - |
| 1968 | plane | - | - | 50 | - | - |
| 1969 | plane | 07/31 | 2,600 | 98 | - | 2,698 |
| 1970 | plane | 07/30 | 7,500 | 20 | - | 7,520 |
| 1971 | plane | 07/29 | 22,000 | - | - | 22,000 |
| 1972 | foot | 07/20 | 100 | - | - | 100 |
| 1973 | plane | - | 300 | - | - | 300 |
| 1974 | foot | 07/12 | 4,300 | - | - | 4,300 |
| 1975 | plane | 07/28 | 10,000 | - | 43 | 10,043 |
| 1976 | plane | 07/02 | 29,000 | 386 | 43 | 29,429 |
| 1977 | plane | 07/29 | 51,300 | - | 2,162 | 53,462 |
| 1978 | weir | 08/24 | 52,701 | 3,414 | 1,632 | 57,747 |
| 1979 | weir | 08/23 | 82,703 | 2,146 | 2,069 | 86,918 |
| 1980 | weir | 08/24 | 93,861 | 28 | 3,352 | 97,241 |
| 1981 | weir | 08/26 | 57,267 | 16,990 | 3,883 | 78,140 |
| 1982 | weir | 08/30 | 123,055 | 21,622 | 3,883 | 148,560 |
| 1983 | weir | 08/11 | 40,049 | 4,349 | 3,425 | 47,823 |
| 1984 | weir | 09/84 | 94,463 | 6,130 | 3,121 | 103,714 |
| 1985 | weir | 09/12 | 53,563 | 1,980 | 6,804 | 62,347 |
| 1986 | weir | 09/12 | 48,328 | 2,585 | 3,457 | 54,370 |
| 1987 | weir | 09/12 | 25,994 | 1,238 | 2,464 | 29,696 |
| 1988 | weir | 09/12 | 39,012 | 14 | 2,253 | 41,279 |
| 1989 | weir | 09/30 | 88,825 | * | 3,045 | 91,870 |
| Mean 1978-1989 | | | 65,471 | 5,500 | 3,196 | 73,321 |

Source: (Roppel 1913-1933; Roelofs 1963; Sheridan 1961; ADF&G, Commercial Fish Division Area Annual Reports, 1966-1989).

*Fishery did not take place due to the Exxon "Valdez" oil spill.

In addition, the commercial and subsistence sockeye salmon harvests averaged 5,500 and 3,196 respectively, since 1978. The highest commercial harvest was 21,622 in 1982 and the highest subsistence harvest was 6,804 in 1985. Since 1978, the total adult return averaged 73,321. Thus, from a historical perspective, and considering an escapement goal of 40,000-60,000, recent Afognak Lake sockeye salmon escapements appear sufficient. However, the average commercial harvest of 5,500 or 7.5% of the total return since 1978 is quite low.

Eggtake Creek and Hatchery Creek are the only two tributaries of Afognak Lake that support sockeye salmon spawning (Figure 2), and a high percentage of spawning appears to occur along the shoreline (Table 8). Of the three years of spawning distribution information, lakeshore spawning accounted for 22.7%, 67.9%, and 59.5% of the total number of sockeye salmon observed.

The majority of adult sockeye salmon migrating into Afognak Lake enter in June (Figure 3). On average (1982-1989), approximately 3,000 sockeye salmon enter in May, 43,000 in June, 14,000 in July, 4,000 in August, and a few hundred enter in September. Thus, Afognak Lake sockeye salmon migration is primarily single modal, with possibly a very weak second run in July.

Five-year-old fish (age classes 1.3 and 2.2) dominate (61.5%) the sockeye salmon return to Afognak Lake, followed by four-year-old fish (age classes 2.1 and 1.2) comprising 25.9% of the total (Table 9). The six-year-old fish comprised 7.8% of the total return. In addtion, in 1987 a small percentage of age-0 freshwater adults were reported. Finally, disease screening of Afognak Lake sockeye salmon revealed a 3% and 0% incidence of IHN virus in 1987 and 1988 respectively, and no level of BKD was found.

Table 8. Estimates of adult sockeye salmon spawning in Eggtake and Hatchery Creeks, and along the lakeshore of Afognak Lake.

| Date | Live | Dead | Total | Percent of total |
|---|---|---|---|---|
| | | **Eggtake Creek** | | |
| 08/23/61 | 3,400 | 200 | 3,600 | 27.3 |
| 09/09/63 | 87 | 842 | 929 | -- |
| 08/23/78 | -- | -- | 12,650 | 22.2 |
| 08/15/79 | 10,824 | 1,500 | 12,324 | -- |
| 1982 | -- | -- | 16,362 | 13.7 |
| | | **Hatchery Creek** | | |
| 08/23/61 | 5,000 | 1,580 | 6,580 | 49.9 |
| 08/24/63 | -- | -- | 4,365 | -- |
| 08/25/78 | -- | -- | 5,666 | 9.9 |
| 08/15/79 | 15,284 | 1,000 | 16,284 | -- |
| 1982 | -- | -- | 31,840 | 26.7 |
| | | **Lakeshore** | | |
| 09/08/61 | -- | -- | 3,000 | 22.7 |
| 09/08/61 | -- | -- | 38,743 | 67.9 |
| 1982 | -- | -- | 70,853 | 59.5 |

Source: 1982 data based on tagging estimates; other year's data based on ground survey counts (Sheridan 1961; Roelofs 1964; Swartz pers. comm. ADF&G-Kodiak; Willette 1984).

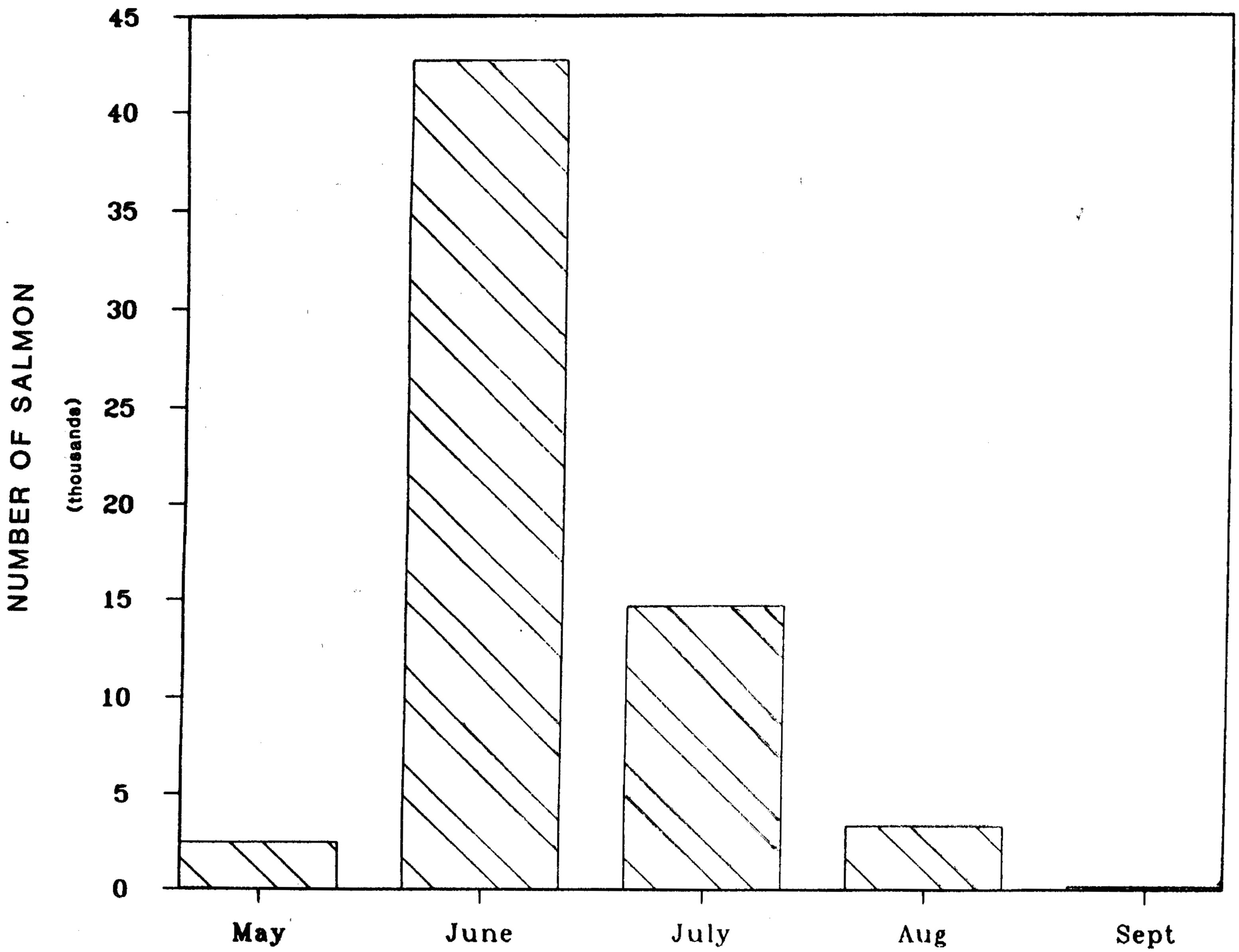


Figure 3. Mean monthly escapement of sockeye salmon into Afognak Lake, 1982-1989.

Table 9. Age composition of adult sockeye salmon sampled from Afognak Lake, 1985-1989.

| | | | Age class | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 0.1 | | 0.2 | | 0.3 | | 1.1 | | 1.2 | | 2.1 | | 1.3 | | 2.2 | | 2.3 | | 1.4 | |
| Year | Stat week | Sample size | No. | % | No. | % | No. | % | No. | % | No. | % | No. | % | No. | % | No. | % | No. | % | No. | % |
| 1985 | 24-30 | 213 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 11,428 | 24.4 | 0 | 0.0 | 24,394 | 52.1 | 5,934 | 12.7 | 4,835 | 10.3 | 220 | 0.5 |
| | 31-38 | 478 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 44 | 0.6 | 1,787 | 25.5 | 0 | 0.0 | 3,003 | 42.9 | 1,890 | 27.0 | 278 | 4.0 | 0 | 0.0 |
| 1986 | 21-39 | 484 | 0 | 0.0 | 0 | 0.0 | 100 | 0.2 | 300 | 0.6 | 4,893 | 10.1 | 100 | 0.2 | 36,150 | 74.8 | 2,796 | 5.8 | 3,895 | 8.1 | 100 | 0.2 |
| 1987 | 28-39 | 281 | 30 | 0.4 | 0 | 0.0 | 0 | 0.0 | 532 | 6.4 | 3,074 | 37.0 | 89 | 1.1 | 3,015 | 36.3 | 355 | 4.3 | 1,212 | 14.6 | 0 | 0.0 |
| 1988 | 22-29 | 508 | 0 | 0.0 | 0 | 0.0 | 55 | 0.2 | 111 | 0.4 | 16,735 | 59.4 | 443 | 1.6 | 8,478 | 30.1 | 2,050 | 7.3 | 277 | 1.0 | 0 | 0.0 |
| | 30-40 | 425 | 0 | 0.0 | 51 | 0.5 | 0 | 0.0 | 152 | 1.4 | 6,324 | 58.6 | 381 | 3.5 | 1,295 | 12.0 | 2,438 | 22.6 | 152 | 1.4 | 0 | 0.0 |
| 1989 | 22-27 | 556 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 5,454 | 8.3 | 10,434 | 15.8 | 2,016 | 3.1 | 30,473 | 46.2 | 12,569 | 19.1 | 4,980 | 7.6 | 0 | 0.0 |
| | 28-38 | 532 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 7,834 | 34.2 | 2,970 | 13.0 | 1,119 | 4.9 | 4,692 | 20.5 | 3,745 | 16.4 | 2,539 | 11.1 | 0 | 0.0 |
| Totals | | | 30 | 0.0 | 51 | 0.0 | 155 | 0.1 | 14,427 | 6.1 | 57,645 | 24.2 | 4,148 | 1.7 | 111,500 | 46.8 | 31,777 | 13.3 | 18,168 | 7.6 | 320 | 0.1 |

## Limnological Assessment

**Light Penetration--** During 1987-1989, photosynthetically active radiation (sunlight) penetrated to a depth ranging from a seasonal average of 8.4 m in 1987 to an average of 12.6 m in 1989 (Table 10). This depth defines the compensation depth (euphotic zone depth [EZD]) for algal photosynthesis. In addition, the Secchi disk depth ranged from 3.0 to 6.0 m, and averaged 4.6 m during 1987-1989. Since the EZD of Afognak Lake was equivalent to, and at times greater than the mean depth, the euphotic volume (EV) is based on the mean depth, and equals 46 X $10^6 m^3$ or 46 EV units.

**Temperature and Dissolved Oxygen Regimes--** The temperature profiles are virtually identical for the two stations, and were combined to characterize the heating and cooling periods. A thermocline was evident during only the month of July during 1987-1989 (Figure 4). The thermocline was less distinct during 1988 than in 1987 or 1989. Thus, during most of the summer season, the lake heats as a homogenous unit to approximately 20 m, with maximum heat content present by the end of July to early August. Because of the relative shallowness of Afognak Lake, and the depth to which mixing occurs, a large volume of water is heated. The surface temperature reached as high as 17° C in early August of 1989, and was still 15° C in September.

For most of the season and depths, dissolved oxygen concentrations ranged between 10-12 mg/L (90 - >100% saturation); however, during the end of July in 1988, concentrations decreased to as low as 5.5 mg/L (50% saturation) near the bottom of the lake (20 m). This concentration is not that unusual considering the high temperature of the lake at 20 m in July (12° C), and is not a serious concern as the epilimnion was well-oxygenated at the time, and by the next sample date in August, the dissolved oxygen was 100% saturated at the 20-m depth.

Table 10. Depth at which photosythesis occurs (one percent light level) and Secchi disc readings for Afognak Lake, 1987-1989.

| Date | Secchi disc (m) Mid-lake | | 1% Light level Mid-lake | |
|---|---|---|---|---|
| 05/26/87 | 5.5 | | 8.2 | |
| 06/26/87 | -- | | 9.3 | |
| 08/07/87 | 3.0 | | 9.3 | |
| 10/10/87 | 5.5 | | 6.9 | |
| Seasonal mean | 4.7 | | 8.4 | |
| | Station 1 | Station 2 | Station 1 | Station 2 |
| 06/10/88 | 4.3 | 4.0 | 9.8 | 10.8 |
| 07/28/88 | 4.5 | 4.3 | 12.8 | 12.3 |
| 08/31/88 | 3.5 | 3.5 | 9.3 | 8.9 |
| 11/03/88 | 4.3 | 4.8 | 16.9 | 14.5 |
| Seasonal mean | 4.2 | 4.2 | 12.2 | 11.6 |
| 06/07/89 | 4.8 | 4.8 | 13.0 | 13.0 |
| 07/07/89 | 4.3 | 5.3 | 15.4 | 15.1 |
| 08/10/89 | 6.0 | 4.0 | -- | -- |
| 09/14/89 | 4.8 | 4.4 | 10.0 | 9.7 |
| Seasonal mean | 5.0 | 4.6 | 12.0 | 12.6 |

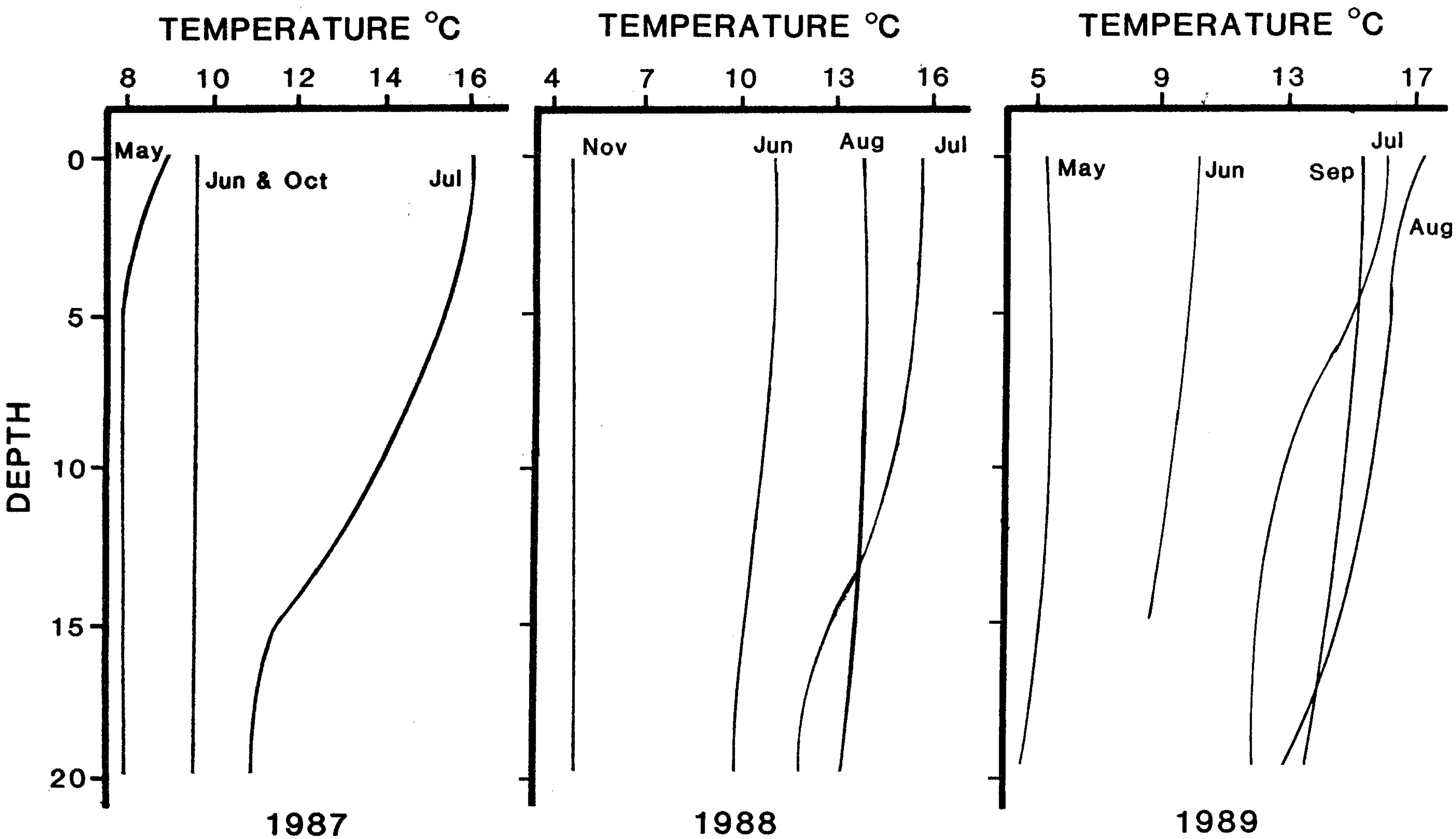


Figure 4. Seasonal temperature profiles for Afognak Lake, 1987-1989.

**General Water Quality Parameters--** Turbidity levels were $\leq$3.0 NTUs, and centered between 0.5 and 1.0 NTUs. Color ranged between 4 and 15 Pt units, was usually between 8 and 9 units (Table 11). Conductivities ranged between 43 and 49 $\mu$mhos/cm in 1987, but were somewhat higher in 1988 and 1989 ranging between 45 and 70 $\mu$mhos/cm. Differences in pH followed the same trend as conductivity, and varied between 6.1 and 7.0 units in 1987 compared to a range of 6.2 to 7.5 units in 1988 and 1989. Alkalinity ranged between 8 and 10 mg/L (as $CaCO_3$) in 1987, and between 8 and 14 mg/L during 1988-1989.

Iron concentrations ranged between 31 and 196 $\mu$g/L, but characteristically ranged between 50 and 60 $\mu$g/L. The concentrations of both calcium (3-4.5 mg/L) and magnesium (0.2-2.0 mg/L) were low, but well within the general range for Alaska lakes.

**Nutrients--** Silicon (Si) ranged between 2,048 and 3,054 $\mu$g/L during 1987-1989 (Table 11) and averaged 2,820 $\mu$g/L as Si. Concentrations at 1 m generally equalled those at 10 to 20 m, and seasonal cycles were not evident. Such consistency is not surprising given the deep euphotic depth (100% of the mean depth), deep water mixing throughout the season, and the oligotrophic nature of the lake. Compared to other Alaskan lakes, silicon levels in Afognak Lake represent high concentrations.

Nitrogen (1 m) in Afognak Lake is divided among organic (58%), ammonium (2%), and nitrate + nitrite (40%). The seasonal mean total Kjeldahl nitrogen (TKN) was 132 $\mu$g/L, and showed little inter-depth variation or seasonal cycle. Nitrate + nitrite (1 m) varied between 18.2 and 207.1 $\mu$g/L, averaged 88 $\mu$g/L, and unlike Si, a seasonal low was observed during the summer. Ammonium ranged from <1.1 to 28.1 $\mu$g/L in the epilimnion (1 m), and averaged 3.8 $\mu$g/L. Compared to other Alaskan lakes inorganic nitrogen levels are intermediate in concentration.

Table 11. General water quality parameters, nutrient concentrations, and chlorophyll a (chl a) concentrations within the epilimnion (1 m) and hypolimnion (10-20 m) of Afognak Lake, 1987-1989.

| Date | 05/27/87 | | 06/26/87 | | 08/07/87 | | 10/06/87 | | 06/10/88 | | | | 07/28/88 | | | | 08/31/88 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Station | 1 | | 1 | | 1 | | 1 | | 1 | | 2 | | 1 | | 2 | | 2 | | 2 | |
| Paramter/Depth | 1 m | 20 m | 1 m | 15 m | 1 m | 15 m | 1 m | 16 m | 1 m | 15 m | 1 m | 10 m | 1 m | 15 m | 1 m | 12 m | 1 m | 15 m | 1 m | 10 m |
| Conductivity (umhos/cm) | 49 | 49 | 47 | 47 | 43 | 43 | 48 | 44 | 49 | 50 | 50 | 50 | 45 | 49 | 47 | 47 | 50 | 50 | 51 | 51 |
| pH | 6.8 | 6.8 | 6.5 | 7.0 | 6.4 | 6.1 | 6.9 | 6.9 | 6.0 | 7.0 | 7.0 | 6.9 | 6.9 | 6.9 | 6.9 | 6.9 | 7.0 | 7.1 | 7.0 | 6.9 |
| Alkalinity (mg/L) | 9 | 10 | 10 | 8 | 11 | 10 | 10 | 10 | 9 | 10 | 8 | 11 | 11 | 12 | 12 | 10 | 11 | 12 | 11 | 11 |
| Turbidity (NTU) | 0.5 | 0.5 | 1.0 | 0.4 | 1.0 | 1.2 | 0.6 | 0.6 | 1.3 | 0.7 | 0.7 | 0.7 | 0.6 | 0.5 | 0.8 | 0.6 | 0.8 | 0.8 | 1.0 | 1.0 |
| Color (Pt) | 7.5 | 7.5 | 8.7 | 9.8 | 7.5 | 8.7 | 5.3 | 4.2 | 14.3 | 9.8 | 15.4 | 13.2 | 9.8 | 7.5 | 8.7 | 6.4 | 8.7 | 9.8 | 14.3 | 11.0 |
| Calcium (mg/L) | 3.6 | 3.6 | 3.6 | 3.6 | 3.6 | 3.6 | 3.5 | 3.5 | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA |
| Magnesium (mg/L) | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.8 | 0.8 | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA |
| Iron (ug/L) | 117 | 68 | 93 | 75 | 53 | 36 | 42 | 53 | 65 | 196 | 85 | 77 | 49 | 44 | 44 | 36 | 32 | 26 | 44 | 136 |
| Total-P (ug/L) | 14.1 | 7.9 | 6.2 | 7.0 | 7.1 | 5.5 | 7.6 | 6.2 | 6.3 | 8.6 | 5.9 | 5.6 | 10.9 | 8.8 | 6.5 | 6.1 | 6.4 | 7.4 | 12.0 | 10.4 |
| TFP (ug/L) | 2.2 | 2.0 | 2.1 | 3.3 | 5.4 | 2.8 | 2.8 | 3.0 | 3.7 | 3.5 | 2.8 | 4.1 | 6.9 | 3.4 | 4.6 | 2.3 | 2.6 | 5.2 | 12.2 | 5.3 |
| FRP (ug/L) | 1.5 | 1.5 | 1.5 | 1.6 | 2.1 | 1.4 | 1.4 | 1.2 | 3.1 | 2.6 | 2.7 | 3.2 | 2.3 | 2.5 | 4.2 | 2.3 | 2.1 | 2.5 | 3.0 | 2.3 |
| TKN (ug/L) | 136.7 | 97.1 | 127.0 | 113.2 | 133.5 | 128.6 | 124.6 | 126.2 | 123.3 | 111.9 | 105.4 | 106.3 | 133.1 | 128.2 | 124.9 | 126.6 | 137.1 | 136.3 | 132.2 | 143.6 |
| Ammonium (ug/L) | 2.1 | 3.2 | 4.5 | 4.2 | 4.2 | 28.1 | 8.4 | 15.6 | 2.8 | 3.3 | 1.2 | 10.3 | 2.2 | 15.2 | 4.8 | 14.4 | 5.3 | 8.7 | 5.3 | 5.9 |
| Nitrate + Nitrite (ug/L) | 207.1 | 211.3 | 155.4 | 151.3 | 91.3 | 143.0 | 85.1 | 85.1 | 106.2 | 113.6 | 101.0 | 93.6 | 32.1 | 61.7 | 38.7 | 56.5 | 31.3 | 36.5 | 32.8 | 39.5 |
| Reactive Si (ug/L) | 3,992 | 3,922 | 3,573 | 3,573 | 3,148 | 3,462 | 2,307 | 2,294 | 2,880 | 2,789 | 2,752 | 2,771 | 2,048 | 2,326 | 2,436 | 2,406 | 2,517 | 2,567 | 2,567 | 2,617 |
| PC (ug/L) | 109 | 127 | 160 | 103 | 163 | 76 | NA | NA | 179 | 156 | 170 | 226 | 301 | 156 | 194 | 202 | 237 | 208 | 132 | 503 |
| TPP (ug/L) | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA |
| Chl a (ug/L) | 0.50 | 0.33 | 0.53 | 0.52 | 0.88 | 0.10 | NA | NA | 1.05 | 0.32 | 0.52 | 0.56 | 1.18 | 0.67 | 1.36 | 0.93 | 1.14 | 0.65 | 1.11 | 0.55 |
| Phaeo a (ug/L) | 0.41 | 0.43 | 0.44 | 0.39 | 0.76 | 0.40 | NA | NA | 0.60 | 0.31 | 0.28 | 0.56 | 0.67 | 0.53 | 0.65 | 0.67 | 0.69 | 0.94 | 0.92 | 1.09 |

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Table 11 continued. General water quality parameters, nutrient concentrations, and chlorophyll a (chl a) concentrations within the epilimnion (1 m) and hypolimnion (10-20 m) of Afognak Lake, 1987-1989.

| Date | 11/03/88 | | | | | 05/04/89 | | | | 06/07/89 | | | | 07/07/89 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Station | 1 | | 2 | | | 1 | | 2 | | 1 | | 2 | | 1 | | 2 | |
| Paramter/Depth | 1 m | 15 m | 1 m | 9 m | 20 m | 1 m | 15 m | 1 m | 12 m | 1 m | 15 m | 1 m | 12 m | 1 m | 15 m | 1 m | 13 m |
| Conductivity (umhos/cm) | 59 | 50 | 56 | 51 | NA | 61 | 62 | 63 | 63 | 66 | 62 | 62 | 62 | 63 | 63 | 63 | 63 |
| pH | 6.7 | 6.7 | 6.7 | 6.7 | NA | 6.2 | 6.5 | 6.5 | 6.5 | 7.4 | 6.9 | 7.0 | 7.0 | 7.3 | 7.1 | 7.2 | 7.0 |
| Alkalinity (mg L/1) | 12 | 11 | 11 | 10 | NA | 8 | 8 | 9 | 8 | 11 | 9 | 9 | 10 | 11 | 11 | 11 | 11 |
| Turbidity (NTU ) | 2.8 | 2.2 | 3.0 | 2.8 | NA | 1.2 | 0.8 | 1.0 | 0.8 | 0.6 | 0.6 | 0.6 | 0.7 | 8.7 | 0.5 | 0.5 | 0.6 |
| Color (Pt) | 13.2 | 11.0 | 8.7 | 11.0 | NA | 8.7 | 9.8 | 10.9 | 8.7 | 10.9 | 8.7 | 9.8 | 8.7 | 0.6 | 9.8 | 9.8 | 8.7 |
| Calcium (mg L/1) | 4.7 | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | 4.5 | 4.5 | 3.6 | 4.5 |
| Magnesium (mg/L) | 1.6 | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | 1.1 | 1.1 | 1.9 | 1.1 |
| Iron (ug/L) | 52 | 59 | 80 | 115 | NA | 58 | 80 | 66 | 72 | 50 | 59 | 53 | 117 | 42 | 48 | 50 | 133 |
| Total-P (ug/L) | 8.6 | 6.2 | 7.4 | 7.1 | NA | 6.2 | 6.1 | 5.8 | 5.0 | 7.3 | 6.0 | 5.5 | 6.4 | 13.1 | 5.9 | 9.2 | 16.6 |
| TFP (ug/L) | 5.4 | 4.3 | 3.0 | 2.9 | NA | 3.5 | 3.5 | 3.9 | 3.7 | 4.1 | 3.8 | 4.8 | 4.0 | 4.5 | 3.9 | 3.3 | 3.9 |
| FRP (ug/L) | 3.2 | 2.7 | 2.3 | 2.4 | NA | 2.2 | 2.3 | 2.3 | 2.3 | 2.2 | 2.8 | 3.5 | 2.8 | 2.7 | 2.6 | 2.8 | 2.3 |
| TKN (ug/L) | 167.2 | 119.2 | 147.7 | 127.4 | NA | 115.6 | 114.8 | 120.4 | 96.3 | 141.3 | 134.8 | 110.8 | 114.8 | 163.0 | 136.5 | 130.8 | 130.8 |
| Ammonium (ug/L) | 6.4 | <1.1 | 2.5 | 3.6 | NA | <1.1 | <1.1 | <1.1 | <1.1 | <1.1 | <1.1 | 1.4 | <1.1 | <1.1 | 7.7 | <1.1 | 10.4 |
| Nitrate + Nitrite (ug/L) | 72.1 | 55.8 | 68.4 | 65.4 | NA | 128.0 | 117.1 | 130.4 | 132.4 | 104.7 | 103.7 | 104.7 | 102.7 | 50.8 | 69.1 | 52.3 | 72.1 |
| Reactive Si (ug/L) | 2,590 | 2,428 | 2,654 | 2,475 | NA | 2,748 | 2,899 | 2,841 | 2,899 | 2,978 | 3,004 | 3,054 | 3,042 | 2,774 | 2,788 | 2,719 | 2,788 |
| PC (ug/L) | 271 | 194 | 237 | 194 | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA |
| TPP (ug/L) | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA |
| Chl a (ug/L) | 3.17 | 6.87 | 3.33 | NA | 6.80 | 0.70 | 0.28 | 0.63 | 0.62 | 0.79 | 0.64 | 0.49 | 0.53 | 0.73 | 0.77 | 0.91 | 0.69 |
| Phaeo a (ug/L) | 0.99 | 2.16 | 1.03 | NA | 1.29 | 0.72 | 0.25 | 0.28 | 0.30 | 0.38 | 0.27 | 0.26 | 0.37 | 0.35 | 0.47 | 0.32 | 0.47 |

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Table 11 continued. General water quality parameters, nutrient concentrations, and chlorophyll a (chl a) concentrations within the epilimnion (1 m) and hypolimnion (10-20 m) of Afognak Lake, 1987-1989.

| Date | 08/03/89 | | | | 09/14/89 | | | |
|---|---|---|---|---|---|---|---|---|
| Station | 1 | | 2 | | 1 | | 2 | |
| Paramter/Depth | 1 m | 15 m | 1 m | 13 m | 1 m | 15 m | 1 m | 12 m |
| Conductivity (umhos/cm) | 63 | 64 | 64 | 66 | 65 | 64 | 64 | 70 |
| pH | 7.2 | 6.8 | 7.2 | 6.7 | 7.1 | 7.1 | 7.1 | 7.5 |
| Alkalinity (mg/L) | 12 | 12 | 12 | 10 | 11 | 11 | 11 | 14 |
| Turbidity (NTU) | 0.8 | 0.7 | 0.8 | 1.2 | 0.7 | 0.7 | 1.0 | 0.6 |
| Color (Pt) | 6.4 | 9.8 | 8.7 | 10.9 | 12.1 | 10.9 | 12.1 | 12.1 |
| Calcium (mg/L) | 3.4 | 4.3 | 4.3 | 4.3 | 4.1 | 4.1 | 3.6 | 4.5 |
| Magnesium (mg/L) | <0.2 | 0.4 | 0.8 | 1.5 | 2.0 | 2.0 | 1.7 | 1.7 |
| Iron (ug/L) | 35 | 31 | 41 | 100 | 33 | 38 | 56 | 34 |
| Total-P (ug/L) | 6.7 | 6.8 | 7.0 | 7.9 | 8.2 | 7.6 | 8.2 | 7.9 |
| TFP (ug/L) | 4.1 | 3.7 | 3.9 | 3.7 | 5.0 | 4.7 | 5.1 | 8.6 |
| FRP (ug/L) | 2.0 | 2.3 | 2.5 | 2.3 | 3.0 | 2.5 | 2.8 | 2.8 |
| TKN (ug/L) | 129.2 | 137.2 | 133.2 | 178.2 | 145.3 | 144.5 | 134.1 | 133.2 |
| Ammonium (ug/L) | <1.1 | 27.4 | <1.1 | 40.1 | 8.8 | 8.8 | 10.4 | 13.0 |
| Nitrate + Nitrite (ug L/1) | 18.2 | 49.3 | 23.6 | 39.4 | 34.5 | 44.9 | 38.5 | 38.0 |
| Reactive Si (ug/L) | 2,440 | 2,678 | 2,500 | 2,642 | 2,631 | 2,644 | 2,644 | 2,694 |
| PC (ug/L) | NA | NA | NA | NA | NA | NA | NA | NA |
| TPP (ug/L) | NA | NA | NA | NA | NA | NA | NA | NA |
| Chl a (ugL) | 1.62 | 0.43 | 0.87 | 0.48 | 0.76 | 1.15 | 0.84 | 1.01 |
| Phaeo a (ugL) | 0.60 | 0.68 | 0.67 | 0.52 | 0.67 | 0.86 | 0.53 | 0.87 |

Throughout the season of 1988 and 1989, total phosphorus (TP) concentrations (1 m) ranged between 5.5 and 14.1 $\mu$g/L (as P) and averaged 8.2 $\mu$g/L, while epilimnetic TP levels in May and June of 1988 and 1989 were about 6 $\mu$g/L. Reactive or (inorganic) phosphorus (FRP) ranged between 1.2 and 4.2 $\mu$g/L in the epilimnion, and averaged 2.3 $\mu$g/L. Thus, FRP comprised 28% of TP and was above detectable levels (0.7 $\mu$g/L) throughout the entire sampling season.

Finally, nutrient ratios (by atoms) in the epilimnion during the open-water period equalled 64:1 for TN:TP, 344:64:1 for Si:N:P and 12.8:1 for Si:N. The desired Si:N:P for phytoplankton growth is 17:16:1. Thus, phosphorus concentrations were low relative to the supply of nitrogen, and conversly, reactive silicon concentrations were high relative to nitrogen.

**Chlorophyll a--** With few exceptions, the algal standing crop (chl a) was low in Afognak Lake during 1987-1989 (Table 11). In the epilimnion (1 m) chl a ranged between 0.49 and 3.33 $\mu$g/L, with the higher concentrations found during November. The seasonal concentration of chl a in the epilimnion averaged 0.97 $\mu$g/L. In the hypolimnion (10-20 m), chl a concentrations ranged between 0.10 and 6.80 $\mu$g/L, and averaged 0.94 $\mu$g/L, or similar to the concentration found in the epilimnion. Chl a concentrations in 1987 were lower, but differences were slight compared to 1988 and 1989.

**Zoolankton Abundance and Size--** The macro-zooplankton community consisted of the cladocerans: *Daphnia longiremus*, *Holopedium gibberum*, and *Bosmina longirostris* along with the copepods: *Cyclops columbianus*, *Diaptomus pribilofensis*, *Epischura nevadensis*, and *Egrasilus* sp. (Table 12). Seasonal mean densities for cladocerans ranged between 41,429 /$m^2$ (1989 station 2) and 144,228/$m^2$ (1987 mid-lake), while *Cyclops* densities ranged between 11,891/$m^2$ (1988 station 2) and 33,202/$m^2$ (1987 mid-lake). Macro-zooplankton was characterized by the dominance of *Bosmina*

Table 12. Macro-zooplankton density (No/$m^2$) by taxa, sample date, and seasonal average for Afognak Lake, 1987-1989.

| | Density (No/$m^2$) | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1987 | | | | | 1988 | | | | | | | | | |
| | | | | | | Station 1 | | | | | Station 2 | | | | |
| Taxa/Date | 05/27 | 06/27 | 08/07 | 10/06 | Seasonal average | 06/10 | 07/28 | 08/31 | 11/03 | Seasonal average | 06/10 | 07/28 | 08/31 | 11/03 | Seasonal average |
| *Bosmina longirostris* | 29,061 | 265,924 | 157,909 | 10,584 | 138,370 | 14,862 | 151,815 | 257,707 | 1,465 | 106,462 | 10,669 | 131,369 | 292,197 | 1,115 | 108,838 |
| *Daphnia longiremus* | 796 | 1,990 | 3,185 | 7,166 | 3,284 | -- | -- | 3,715 | 133 | 962 | -- | 2,118 | 3,185 | 318 | 1,405 |
| *Holopedium gibberum* | 876 | 5,175 | 3,981 | 265 | 2,574 | 265 | 3,185 | 1,327 | 133 | 1,228 | 159 | 2,919 | 531 | 159 | 942 |
| Subtotal | 30,733 | 273,089 | 165,075 | 18,015 | 144,228 | 15,127 | 155,000 | 262,749 | 1,731 | 108,652 | 10,828 | 136,406 | 295,913 | 1,592 | 111,185 |
| *Cyclops columbianus* | 4,697 | 6,768 | 2,389 | 2,389 | 4,061 | 4,512 | 4,777 | 3,185 | 265 | 3,185 | 1,592 | 796 | 531 | 318 | 809 |
| *Diaptomus pribilofensis* | 159 | -- | -- | 531 | 173 | -- | -- | -- | -- | -- | 159 | -- | -- | -- | 40 |
| *Egrasilus* sp. | -- | -- | -- | 531 | 133 | -- | -- | -- | 265 | 66 | -- | 1,067 | -- | 478 | 386 |
| *Espischura nevadensis* | 20,064 | 62,102 | 32,909 | 265 | 28,835 | 28,132 | 45,648 | 15,393 | 265 | 22,360 | 12,898 | 18,312 | 11,412 | -- | 10,656 |
| Subtotal | 24,920 | 68,870 | 35,298 | 3,716 | 33,202 | 32,644 | 50,425 | 18,578 | 795 | 25,611 | 14,649 | 20,175 | 11,943 | 796 | 11,891 |
| Total | 55,653 | 341,959 | 200,373 | 21,731 | 177,430 | 47,771 | 205,425 | 281,327 | 2,526 | 134,263 | 25,477 | 156,581 | 307,856 | 2,388 | 123,076 |

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Table 12 continued. Macro-zooplankton density (No/$m^2$) by taxa, sampled date, and seasonal average for Afognak Lake, 1987-1989.

| | Density (No/$m^2$) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1989 | | | | | | | | | | | |
| | Station 1 | | | | | | Station 2 | | | | | |
| Taxa/Date | 05/04 | 06/07 | 07/07 | 08/03 | 09/14 | Seasonal average | 05/04 | 06/07 | 07/07 | 08/03 | 09/14 | Seasonal average |
| *Bosmina longirostris* | 265 | 9,156 | 68,599 | 128,185 | 141,985 | 69,638 | -- | 5,441 | 58,183 | 137,739 | 87,049 | 40,473 |
| *Daphnia longiremus* | 531 | -- | 133 | 3,981 | 4,246 | 1,778 | 398 | -- | -- | 1,062 | 1,062 | 292 |
| *Holopedium gibberum* | -- | 633 | 3,185 | 1,327 | 1,592 | 1,347 | -- | 398 | 2,389 | 531 | -- | 664 |
| Subtotal | 796 | 9,789 | 71,917 | 133,493 | 147,823 | 72,763 | 398 | 5,839 | 60,572 | 139,332 | 88,111 | 41,429 |
| *Cyclops columbianus* | -- | 5,441 | 5,573 | 2,389 | 796 | 2,840 | 3,185 | 1,194 | 1,592 | 1,327 | 265 | 1,460 |
| *Diaptomus pribilofensis* | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| *Egrasilus* sp. | -- | -- | 1,062 | 1,062 | 531 | 531 | -- | -- | 531 | 265 | 1,062 | 159 |
| *Espischura nevadensis* | -- | 14,862 | 4,114 | 58,386 | 4,246 | 16,322 | 133 | 4,379 | 7,166 | 48,567 | 1,592 | 12,049 |
| Subtotal | 0 | 20,303 | 10,749 | 61,837 | 5,573 | 19,693 | 3,318 | 5,573 | 9,289 | 50,159 | 2,919 | 13,668 |
| Total | 796 | 30,092 | 82,666 | 195,330 | 153,396 | 92,456 | 3,716 | 11,412 | 69,861 | 189,491 | 91,030 | 55,097 |

beginning in mid-June, and peaking the end of June in 1987, early August in 1988, and the end of August in 1989. In general, by late summer when the lake temperature peaked, *Bosmina* flourished and attained peak densities. Over the season, *Bosmina* accounted for 80% of the total density of macro-zooplankton. Early in the year (late May-early June), the macro-zooplankton community was dominated by the copepod *Epischura*, which appeared somewhat stable in relative density throughout the season, except during and after September when densities declined. Of the copepods, *Epischura* dominated and accounted for 15% of the total macro-zooplankton. The cladoceran:copepod ratio was 5.3:1 on a seasonal basis during 1987-1989, although a lower ratio was apparent in the spring (May-June) period.

Body sizes of *Bosmina* (Table 13) averaged 0.31 mm and never exceeded 0.4 mm, which is considered the threshold size for elective consumption by sockeye salmon fry (Koenings and McDaniel 1983). Thus, full utilization of the this food item is apparent. The body size of *Daphnia* ranged between 0.44 and 0.65 mm, and *Holopedium* ranged in size between 0.46 and 0.52 mm. For the copepods, which are generally not consumed when adequate numbers of cladocerans are present, body sizes were not as depressed compared to the cladocerans, suggesting less demanding utilization. For example, *Cyclops* ranged in body size from 0.64 to 0.70 mm throughout the season, *Diaptomus* ranged between 1.01 and 1.44 mm, and the more abundant *Epischura* ranged from 0.91 to 0.99 mm.

## EVALUATION

**Potential Sockeye Salmon Production--** The first estimate of sockeye salmon production is derived from the spawning area for the tributaries used by sockeye salmon, and the useable lakeshore of Afognak Lake, calculated from actual measurements of stream width and length, and spawning gravel quality (Blackett[1],

Table 13. Macro-zooplankton length (mm) by taxa, sample date, and seasonal weighted mean for Afognak Lake, 1987-1989.

| | Mean length (mm) | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | 1988 | | | | | | | | | |
| | 1987 | | | | | Station 1 | | | | | Station 2 | | | | |
| Taxa/Date | 05/27 | 06/27 | 08/07 | 10/06 | Seasonal weighted mean | 05/27 | 06/27 | 08/07 | 10/06 | Seasonal weighted mean | 06/10 | 07/28 | 08/31 | 11/03 | Seasonal weighted mean |
| *Bosmina longirostris* | 0.36 | 0.31 | 0.33 | 0.36 | 0.33 | 0.36 | 0.31 | 0.33 | 0.36 | 0.33 | 0.36 | 0.34 | 0.33 | 0.35 | 0.33 |
| *Daphnia longiremus* | 0.50 | 0.63 | 0.62 | 0.48 | 0.54 | 0.50 | 0.63 | 0.62 | 0.48 | 0.54 | -- | 0.70 | 0.64 | 0.47 | 0.65 |
| *Holopedium gibberum* | 0.49 | 0.54 | 0.50 | 0.64 | 0.52 | 0.49 | 0.54 | 0.50 | 0.64 | 0.52 | 0.45 | 0.55 | 0.64 | 0.36 | 0.55 |
| Subtotal | | | | | | | | | | | | | | | |
| *Cyclops columbianus* | 0.51 | 0.58 | 0.86 | 0.87 | 0.64 | 0.51 | 0.58 | 0.86 | 0.87 | 0.64 | 0.61 | 0.77 | 0.92 | 0.60 | 0.70 |
| *Diaptomus pribilofensis* | 1.10 | -- | -- | 0.98 | 1.01 | 1.10 | -- | -- | 0.98 | 1.01 | 1.44 | -- | -- | -- | 1.44 |
| *Egrasilus* sp. | -- | -- | -- | 0.69 | 0.69 | -- | -- | -- | 0.69 | 0.69 | 00 | 0.54 | 0.57 | 0.61 | 0.56 |
| *Espischura nevadensis* | 0.62 | 1.05 | 0.83 | 1.05 | 0.91 | 0.62 | 1.05 | 0.83 | 1.05 | 0.91 | 0.76 | 1.05 | 1.10 | -- | 0.98 |
| Subtotal | | | | | | | | | | | | | | | |
| Total | | | | | | | | | | | | | | | |

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Table 13 continued. Macro-zooplankton length (mm) by taxa, sample date, and seasonal weighted mean for Afognak Lake, 1987-1989.

| | 1989 | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean length (mm) | | | | | | | | | | | |
| | Station 1 | | | | | | Station 2 | | | | | |
| Taxa/Date | 05/04 | 06/07 | 07/07 | 08/03 | 09/14 | Seasonal weighted mean | 05/04 | 06/07 | 07/07 | 08/03 | 09/14 | Seasonal weighted mean |
| Bosmina longirostris | 0.35 | 0.31 | 0.32 | 0.31 | 0.30 | 0.31 | -- | 0.29 | 0.30 | 0.31 | 0.30 | 0.31 |
| Daphnia longiremus | 0.80 | -- | 0.40 | 0.69 | 0.58 | 0.64 | 0.66 | -- | -- | 0.62 | 0.62 | 0.63 |
| Holopedium gibberum | -- | 0.50 | 0.47 | 0.45 | 0.50 | 0.48 | -- | 0.48 | 0.47 | 0.39 | -- | 0.46 |
| Subtotal | | | | | | | | | | | | |
| Cyclops columbianus | 0.52 | 0.59 | 0.72 | 0.93 | 0.69 | 0.70 | 0.57 | 0.55 | 0.69 | 0.95 | 0.58 | 0.66 |
| Diaptomus pribilofensis | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Egrasilus sp. | -- | -- | 0.53 | 0.57 | 0.61 | 0.56 | -- | -- | 0.63 | -- | 0.61 | 0.63 |
| Espischura nevadensis | -- | 0.68 | 0.91 | 1.07 | 1.02 | 0.99 | 0.90 | 0.69 | 1.08 | 0.90 | 0.80 | 0.91 |
| Subtotal | | | | | | | | | | | | |
| Total | | | | | | | | | | | | |

personal communication). Results of that survey indicate that Hatchery Creek has a total of 9,712 $m^2$ of useable spawning area and Eggtake Creek has 6,595 $m^2$. Based on an optimum spawning density of 2.0 $m^2$ per female (Burgner et al. 1969), Hatchery Creek would be capable of supporting 4,856 female spawners, and Eggtake Creek could support 3,297 females. Although the spawning area available on the lakeshore is more difficult to estimate than in the tributaries; the total lakeshore spawning area was estimated at 50,000 $m^2$, which could support 25,000 females. Thus, the total number of desired spawners based on a 50:50 sex ratio is 66,000, comprised of 50,000 lakeshore spawners and 16,000 tributary spawners.

Considering that the mortality of tributary spawners can be as high as 10% in small tributaries like Eggtake and Hatchery Creeks due to brown bear (*Ursus arctos*) predation (Barrett[2], personal communication), 60,000 viable spawners would be predicted as the capacity of Afognak Lake based on spawning area. In addition, assuming a 50:50 sex ratio, a fecundity of 2,500 eggs/female (Roelofs 1964), and a potential egg deposition to emergent fry survival ranging from 3.9% (Drucker 1970) to 10% (Koenings et al. 1988); an estimated recruitment between 3 and 7 million sockeye salmon juveniles would enter into Afognak Lake each year.

Secondly, using experimental results of stocking and nutrient enrichment on Leisure Lake in Cook Inlet, an empirical model based on euphotic volume (Koenings and Burkett 1987) was developed to predict the maximum and optimum number of sockeye salmon fry that nursery lakes could support. Maximum stocking density was found to be 110,000 fry per euphotic volume (EV) unit, and optimum stocking density was defined as 54,000 fry per EV unit. Using this rearing capacity model, Afognak Lake, which has 46 EV units, would support between 3 and 5 million sockeye salmon fry, from an escapement of about 46,000 adults.

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[1]Aquatech, P. O. Box 593, Kodiak, AK 99615.

[2]ADF&G, Commercial Fish Division, 211 Mission Road, Kodiak, AK 99615-6399.

Thirdly, based upon the relationship between seasonal mean zooplankton (fish forage) biomass and resultant sockeye salmon smolt biomass yield for numerous lakes throughout Alaska; Afognak Lake, with 154 $mg/m^2$ of zooplankton biomass would be expected to produce 1,630 kg of sockeye salmon smolt biomass. If one considers the 400,000 population estimate of juvenile fish in the spring of 1989 (Table 3) was comprised mainly of sockeye salmon pre-smolts, the estimated smolt biomass would be 1,640 kg, which is very similar to the forage biomass estimate.

Thus, Afognak Lake appears to be fully utilized as potential fry recruitment, based on spawning capacity, is very similar to both the estimated number of spring juveniles the lake's nursery area can support based on the euphotic volume, and on smolt biomass production based on observed zooplankton biomass. Moreover, substantial increases in escapements over the desired level, (e.g., 1982 and 1984) have not improved returns. In addition, the high parent escapement of 94,463 in 1984 may have caused a larger number of pre-smolts to overwinter another year for rearing, resulting in a high percentage of age-2 smolts observed in 1987. Conversely, the parent escapement of 48,000 in 1986 produced a dominance of age-1 smolts in 1988. Finally, the length and weight of smolts recently sampled from Afognak Lake are slightly below the desired smolt size of 85-90 mm or ~5 g for optimum marine survival (Koenings and Burkett 1987), further suggesting complete utilization of the forage base.

Consequently, to increase the production of sockeye salmon smolts from this system, the rearing capacity must be expanded. One of the most efficient techniques to enlarge the capacity of a lake's rearing environment is through nutrient enrichment. With nutrient enrichment, the rearing capacity can potentially double (Koenings and Burkett 1987), which in the case of Afognak Lake could produce a total adult return of 120,000 fish. This return would provide 60,000 sockeye salmon for the escapement and an additional 60,000 for commercial and subsistence harvest.

The substantial benefit of nutrient enrichment can easily be envisioned, as this enhancement activity would cost only ~\$30,000 each year, and the harvest of ~60,000 sockeye salmon would be valued (ex-vessel dollars) at \$600,000, for a primary benefit-to-cost ratio of 20:1. In addition, providing more sockeye salmon for the subsistence fishery has a significant social value, but one which is difficult to estimate.

## RECOMMENDATIONS

Nutrient enrichment for Afognak Lake is recommended based on the following findings and premises:

1) The light regime and the depth of mixing essentially encompass the entire lake depth, so nutrients are continually recirculated within the euphotic trophogenic zone without seasonal loss to a non-mixing hypolimnion.

2) The short residence time (0.4 yr) of the lake water, especially during the summer growing period, rapidly depletes the supply of nutrients needed by phytoplankton.

3) The natural production of millions of voracious sockeye salmon fry fully utilize the current standing stock of macro-zooplankton, thereby reducing the zooplankton grazing pressure on phytoplankton.

4) However, with the release of heavy grazing pressure on phytoplankton by reduced (fully utilized) zooplankton, a larger demand would be placed on available nutrients.

5) An increase in phytoplankton demand for nutrients would be alleviated by nutrient enrichment.

6) Phosphorus levels are low, but on average the Si:N:P ratios are acceptable (334:64:1), relative to the desired ratio of 17:16:1 for ideal phytoplankton growth.

7) Finally, increased primary and secondary production levels through nutrient enrichment would increase the rearing capacity for juvenile sockeye salmon.

In nearly a dozen lakes previously enriched with nitrogen and phosphorus, the prevailing methodology was to apply sufficient phosphorus each year to reach 90% of the minimal critical loading (Vollenweider 1976). Similarly, a loading rate of 90% of the minimum loading rate is suggested for Afognak Lake. The existing loading rate of phosphorus (P) into Afognak Lake has averaged 211 mg $P/m^2/yr$. The 90% rate of the critical loading of P is 316 mg $P/m^2/yr$, thus, allowing for the addition of 105 mg $P/m^2/yr$ or 557 kg P. Because of seasonal peaks, additions of phosphorus to Afognak Lake would comprise of adding 13,208 kg (13 tons) of a liquid product (20-5-0) containing 20% nitrogen, 5% phosphorus, and 0% potash during 15 May-01 July. In addition, 20,463 kg (20 tons) of nitrogen (32-0-0), in a composition of one-third inorganic nitrogen, organic nitrogen, and ammonium would be applied during 01 July-01 September. Finally, the additions would take place every three days, and be located in the upper-middle area of the lake.

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